

Assessment and prevention of radioactive risk due to ^{222}Rn on university premises in Genoa, Italy

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Key words

Radioactivity • Radon • Work Environment

Summary

From October 2004 to September 2005, Radon²²² activity in high-risk indoor spaces used by employees and students at the University of Genoa was measured with CR-39 nuclear track detectors. The mean concentration in winter ($78.9 \text{ Bq/m}^3 \pm 74.92 \text{ S.D.}$) was low in relation to the microenvironment considered. When data were broken down by type and location of the spaces, no significant differences were found, despite the fact that the Genoa conurbation lies on soil of variable geological composition. The dose absorbed by employees was

0.42 mSv/year, with a relative risk of 4.2/1000 cases of Radon-related lung cancer. The dose absorbed by students was 0.28 mSv/year, with a relative risk of 2.5/1000 cases of Radon-related lung cancer. The level of radon activity detected never exceeded the limit of 500 Bq/m^3 established by Italian law. Nevertheless, the value of the compound uncertainty index suggested that the real level of Radon contamination could have exceeded 400 Bq/m^3 in selected spaces, a value requiring annual concentration tests.

Introduction

Radon is the main source of human exposure to ionising radiation of natural origin because it is concentrated in the indoor microenvironment. The health risks due to radon exposure are linked to its short-lived alpha-emitting offsprings, which interact both chemically and physically with the organism. Damage to the tissues of the respiratory apparatus, in particular the epithelium of the bronchi, segmental bronchioles and alveolar membranes, may ensue. The bronchial epithelium is the most important target, and the site of the most common radiation-related lung tumours [1-5].

Radon found in indoor environments originates from (a) gaseous discharge from the earth, building material (walls, floors, and ceilings), (b) running water, and (c) natural gas. Its indoors concentration is influenced by numerous variables. These can be subdivided into two groups: a) variables directly correlated with the concentration of radon precursors in the earth and in building materials [6, 7] and b) variables related to the degree of air exchange and the personal habits of the occupants [8, 9].

After residential buildings, the second most important source of radon exposure is the workplace, where employees spend from 8 to 10 hours a day at work. For this reason, Italian law (Decree 241/2000) has implemented the 96/29/EURATOM directive regarding the protection of the health of the population and of workers against the risks caused by ionising radiation [10]. The legislature emphasises the need to ascertain concentration of radon and its offspring in workplaces at high risk of exposure [11, 12].

In our university, many research laboratories and lecture theatres are located on the ground floor, or in basements with limited window area. Since employees and students often spend there many hours, these spaces should be regarded as being at risk of radioactivity exposure. The aim of the present study was to identify the variables governing the concentration of radon in these confined spaces and to calculate the dose absorbed by the population. The dose values were used as a basis for assessing the radioactive risk and for identifying any primary preventive measures deemed necessary.

Materials and methods

The study was broken down into the following phases:

- planning of sampling;
- sampling and analyses;
- statistical elaboration of results;
- risk evaluation.

PLANNING OF SAMPLING

The confined spaces to be analysed were selected on the basis of the following features: a) proximity to the ground (underground, partly underground, ground-floor), b) type of use (i.e., warehouses and storage rooms were not included) and c) feasibility of dosimeter setting (tamper-proof location).

Radon concentration was assessed during the winter period (measurements over 4 months), followed by further measurement during the summer period in those settings that proved to be the most contaminated during the first monitoring campaign.

SAMPLING AND ANALYSIS

During the winter period, 82 sites located in academic buildings in various parts of the city of Genoa were sampled. They were classified according to the city district in order to take into consideration the “ground” variable. Detectors were installed on 28 October 2004, and were collected on 28 February 2005.

In the summer period, the 18 sites that had previously proved to be the most contaminated were re-examined. The detectors remained in place from 20 May 2005 to 16 September 2005.

The CR-39 nuclear track detector method was used to determine the radon concentration [13]. The detectors were collected shortly before chemical development. A total of 100 analyses were carried out.

STATISTICAL ELABORATION OF RESULTS

Figure 1 shows the frequency distribution of the data subdivided by class; this reveals the log-normal trend that is typical of indoor radon contamination. In the subsequent statistical workup, the data were log-transformed. Significance in the differences among the means was evaluated by analysis of variance (ANOVA). Sheffé’s test was used to compare several means. Each analysis included a compound uncertainty (CU) calculated according to the following formula:

$$(sm^2 + sr^2)^{0.5} \quad [1]$$

where:

sm is the measurement uncertainty associated with the entire process

sr is the uncertainty associated with the repetition of measurements

EFFECTIVE DOSE CALCULATION

The effective dose (EC) received by the population was calculated as suggested by UNSCEAR (2000) [14]:

$$EC = CR_n \times F \times HC \times DC \quad [2]$$

where CR_n is the ²²²Rn indoor concentration ($Bq\ m^{-3}$), F the equilibrium factor, HC occupancy ($h\ y^{-1}$), and DC the dose coefficient [$nSv\ (Bq\ h\ m^{-3})^{-1}$].

Since experimental values of F are unknown for Genoa, a default value of 0.4 was applied, as suggested by UNSCEAR (2000) [14]. A mean value of $9\ nSv\ (Bq\ h\ m^{-3})^{-1}$ for DC has been reported by UNSCEAR (2000). In order to evaluate the equivalent of the effective dose, we assumed that workers occupied the sites for a mean of 1,936 hours/year (corresponding to 8 hours/day for 22 days monthly for 11 months/year) and that students occupied them for a mean 1,320 hours/year (corresponding to 6 hours/day for 22 days monthly for 10 months/year).

RISK EVALUATION

To evaluate the relationship between the induction of tumours and the concentration of radon in the indoor sites, the risk factor proposed by ICRP was employed [1], which assumes a life expectancy of about 77 years (80 for women and 74 for men) and uses the equilibrium factor (F) = 0.4, mentioned above. The resulting risk factor is about $7 \cdot 10^{-5}$ [3] cases of lung cancer for every becquerel of radon²²² in the inhaled air.

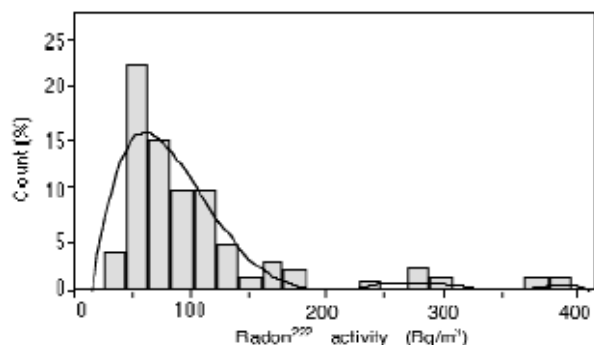
Results

The mean winter concentration of radon in the sites analysed was $78.9\ Bq/m^3 \pm 74.92\ S.D.$, with a compound uncertainty (CU) of 12.2% associated with each measurement. The maximum value recorded was $387.0 \pm 46.4\ (CU)\ Bq/m^3$; the minimum was $9.7 \pm 1.2\ (CU)\ Bq/m^3$.

The following table reports the winter concentrations of radon subdivided according to the type of environment analysed (Tab. I).

Sheffé’s test did not reveal any significant differences among the various types of environment.

Fig. 1. Frequency distribution of the indoor radon concentration (Bq/m^3).



Tab. I. Winter concentrations of radon (Bq/m^3) broken down by type of environment.

Type	Arithmetic mean	$\pm S.D.$
Underground	94.59	113.73
Partly underground	76.56	74.05
Ground floor	82.57	66.14

Tab. II. Winter concentrations of radon (Bq/m^3) broken down by city district in Genoa.

District	Arithmetic mean	$\pm S.D.$
S. Martino	102.52	101.73
Albaro	63.14	41.52
Centro	82.46	70.45
Balbi	44.40	22.93

Tab. III. Mean concentrations of radon subdivided into the two periods of analysis in the environments analysed in both periods.

Seasons	Arithmetic mean	± S.D.
Winter	179.53	97.19
Summer	70.49	54.40

Table II shows the winter concentrations of radon subdivided according to the district in which the buildings examined are located. This subdivision utilises city district boundaries in order to highlight the importance of the “ground” variable for radon precursors in the soil. Sheffé’s test did not reveal any significant differences among the various city districts.

Table III shows the winter and summer concentrations of radon in those sites analysed in both seasons.

Sheffé’s test revealed a highly significant difference between the summer and winter concentrations.

When sites were analysed in both periods, the mean concentration of radon recorded during the summer proved to be about half that in winter (Tab. III). On the basis of this relationship, we calculated the theoretical summer values in the environments that were not analysed in both periods, in order to calculate the mean annual values to be used in calculating the dose absorbed by workers and students. To calculate these absorbed doses, we utilised the formula [2] (Tab. IV).

For workers, the relative risk, calculated on the basis of the mean annual values and of the risk factor reported by the [1], proved to be of 4.2 cases of cancer of the respiratory apparatus due to the inhalation of radon on 1000 cases of lung cancer.

Considerations and conclusions

The general mean indicates that the level of radon contamination in the environments examined is in line with the national mean of 70 Bq/m³. If, however, we consider the types of sites analysed, their radon values cannot be regarded as high. Previous studies conducted by the Department of Health Sciences on Genoese commercial enterprises located in building types similar to those examined in the present study revealed lower concentrations, the mean value being 35.6 ± 25.2 S.D. Bq/m³ [15]. Further research carried out in residential buildings in Genoa recorded a low mean level of con-

tamination (17.1 ± 12.6 Bq/m³). It should be noted, however, that residential buildings are less vulnerable to radioactive contamination, in that most apartments are located high above ground level [16].

The marked non-uniformity in contamination levels, even in sites located relatively close together, is probably linked to variability in the concentrations of radon precursors in the underlying soil. In fact, the Genoa area displays a variety of geological conformations, with exceedingly diverse concentrations of the radioactive families of uranium-238 and thorium-232.

The lack of significance in the differences between underground/partly underground sites in comparison with ground level sites is probably due to high data variability, an effect of the geological conformation of the Genoa area. Our results are also in keeping with those of other studies for the difference in contamination levels between summer and winter [17, 18] samples. The lower summer values can be ascribed to the increased ventilation achieved when the outdoor temperature is higher [19].

Radon contamination is linked to many factors, some of which cannot be easily identified or quantified, and which are associated not only to physical/chemical parameters (the presence of precursors in the soil) but also to individual factors (the personal habits of the concerned population). One such factor is the degree of ventilation of the sites, a variable which significantly influences the indoor radon concentration.

In no case did we record levels of radon activity higher than the limit of 500 Bq/m³ specified by Italian law (D.L. 241/2000). Legally, higher radon concentrations must be reported a qualified expert appointed to evaluate the effective dose absorbed by each member of the concerned population. The fact that the compound uncertainty (CU) index is associated to the measurements means that, in some sites, the real contamination level may be above 400 Bq/m³. Such values mandate annual repetition of the analysis. Moreover, not even in the most contaminated environments did the doses absorbed by employees and students exceed the maximum admissible values reported by the ICRP (2000).

The doses absorbed by employees, which never exceeded 0.55 mSv/year, corresponded to relatively low values considering the legal threshold of 10 mSv/year. Nevertheless, it represented about 1/4 of the individual mean dose absorbed by the general population (2.0 mSv/year). The health impact of radon exposure in these work sites was modest with regard to the long-term effects, the most dangerous risk of ionising radiation.

Tab. IV. Mean doses absorbed by workers and students, subdivided according.

Category	General mean	Doses (mSv/year)			
		San Martino	Albaro	Centro	Balbi
Workers	0.42	0.55	0.35	0.45	0.24
Students	0.28	0.38	0.23	0.30	0.16

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